Role of the Convection Parameterization in AGCM Simulations of Idealized Tropical Cyclones

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Overview
Using General Circulation Models (GCMs) for tropical cyclone studies is difficult due to the relatively small size of the storms, intense convection and multitudes of large-scale small-scale interactions. These are mostly unresolved at typical GCM resolutions of about 50-100 km, and still challenged at high resolutions between 12-30 km. Nevertheless, high-resolution GCMs are becoming a tool of choice to evaluate tropical cyclones in current and future climate simulations. Therefore, the physical and dynamical components of a GCM need to be carefully evaluated to assess their fidelity for tropical cyclone studies.

We implement an idealized tropical cyclone test case for high-resolution GCMs in aqua-planet mode (Neale and Hoskins, 2000) with constant sea surface temperatures of 29°C. The initial conditions are based on an initial vortex seed that is in gradient-wind and hydrostatic balance and intensifies over a 10-day period. The impact of the convection physics package on the evolution of the tropical cyclone is assessed. In particular, we investigate different physics packages within the National Center for Atmospheric Research’s (NCAR) hydrostatic Finite-Volume (FV) Community Atmospheric Model (CAM), including CAM 3.1 (Collins et al., 2004) and CAM 4 (Neale et al., 2010) physics. In addition, we assess a simple physics suite that only incorporates surface fluxes, turbulence, convection, and large-scale precipitation as the driving mechanisms. The research thereby isolates and reveals the influences of the physics schemes on the evolution of the cyclone.

Simple Physics Suite
The simple physics package provides a tool for sensitivity studies, especially with respect to varying physics parameterizations. It contains selected physical processes that drive tropical cyclones, including parameterizations of large-scale convection, convection, surface fluxes and boundary layer turbulence. A benefit of simple physics is that each individual parameterization can be turned on and off, allowing for the examination of the role of each physical process.

Large-Scale Combustion: This approach is based on that used in many GCMs without cloud stage and it rains when a grid box becomes saturated. The rain falls directly to the ground and there is no evaporation.

Convection: This scheme replicates the simplified Betts-Miller relaxation scheme in Frierson (2007). The scheme includes deep convection and three shallow convection options: (1) shallow convection, (2) shallow and (3) quiescent. The differences between (2) and (3) are the reference profiles for temperature and specific humidity, and height to which the profiles are relaxed.

Surface Fluxes: The aerodynamic bulk formulae parameterize the surface flux as

\[ X = -K \left( f_x - f_X \right), \]

where \( X \) represents any of the prognostic variables including the zonal and meridional velocity, temperature and specific humidity, \( f_x \) is a dimensionless exchange coefficient and \( f_X \) the horizontal wind speed. The subscripts \( x \) and \( X \) represent the values at the lowest model level and the surface, respectively. The surface flux acts as the lower boundary condition to the boundary layer. The subscripts \( x \) and \( X \) are dependent on the horizontal wind speed at the lowest model level.

Evolution of the Tropical Cyclone: Comparison of the Wind Speeds

Figure 1: Initial wind speed displayed as (a) a horizontal cross section at a height of 100 m and (b) a longitude-height cross section through the center latitude of the vortex.

Results/Conclusions
It is apparent that the choice of GCM physics parameterizations has a significant impact on the evolution of the tropical cyclone.

• Figure 2 shows that as the resolution increases, the simulated tropical cyclone intensity at day 10 increase when the simple physics package is used. This is also true of the CAM physics packages (not shown).

• The simple physics package can be used to test the sensitivity to different parameterizations (shown with convection in Fig. 2). The differences in the development, intensity and structure of the tropical cyclone when using CAM 3.1 physics compared to CAM 4 physics are notable, as seen in Fig. 3 (Reed and Jablonowski, 2011). However, the difference between the simple physics run and full physics runs are comparable.

• Figure 4 shows that for the simple physics simulations the total precipitation is drastically different by day 10, whereas the wind intensity differences are comparable (Fig. 3). This is due to the large reduction in complexity of the simple physics package.

References

